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FIELD AND PILLAR STRESS DETERMINATIONS AT CAMPBELL RED LAKE MINE, ONTARIO

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by

B. Arjang*

ABSTRACT

At Campbell Red Lake Mine, Northwestern Ontario, rockburst activities were experienced in some mined-out workings. High ground stress, in conjunction with the excavation geometry, appeared to be significant parameters in the context of the underground instability. To determine the stress pattern, three-dimensional field stress measurements were carried out on the 14, 22 and 27 levels (625 m, 990 m and 1220 m below surface), and biaxial stresses were measured in four boxhole pillars on the 9, 10 and 14 levels.

Field stress determination resulted in the following vertical, σ_v, average horizontal, σ_{Ha}, stress gradients and stress ratios, σ_{Ha}/σ_v:

Depth	σ_v	σ_{Ha}	σ_{Ha}/σ_v
625 m:	0.0224 MPa/m	0.0304 MPa/m	1.4
990 m:	0.0253 MPa/m	0.0348 MPa/m	1.5
1220 m:	0.0254 MPa/m	0.0467 MPa/m	1.8

The determined vertical and average horizontal stress increases with depth follow the trend observed for Northern Ontario.

The maximum principal compressive stress, σ_1, is horizontal in the northeasterly direction. With regard to the steeply dipping ore zones with northwest to northerly trend, σ_1 is nearly orthogonal.

The pillar stress determination shows that the maximum stress transfer occurs horizontally across the boxhole pillars, perpendicular to the hanging wall and footwall. Maximum stress magnitudes of 17 to 78 MPa, and minimum stresses of low order or tensional were measured. The pillar stresses were less than expected. It is concluded that the peak strength of the boxhole pillars has been exceeded and that these are in post-failure conditions.

The pillar stresses were not higher than the general field of in situ stress obtained at Campbell Red Lake Mine.

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DÉTERMINATION DES CONTRAINTES DANS LES PILIERS ET DES PRESSIONS DU TERRAIN À LA MINE CAMPBELL DE RED LAKE (ONTARIO)

par

B. Arjang*

RÉSUMÉ

Des coups de toit se sont produits dans les vieux travaux à la mine Campbell à Red Lake dans le nord-ouest de l'Ontario. Les contraintes élevées du terrain combinées avec la géométrie de l'excavation semblent être des paramètres importants de l'instabilité souterraine. Dans le but de déterminer la répartition des contraintes, des mesures tridimensionnelles des pressions du terrain ont été effectuées aux niveaux 14, 22 et 27 (625 m, 990 m, et 1 220 m) sous la surface et les contraintes biaxiales ont été mesurées dans 4 piliers au point de soutirage aux niveaux 9, 10, et 14.

La détermination des contraintes sur le terrain a donné les gradients de contrainte verticaux, σ_v, horizontaux moyens, σ_{Ha}, et les taux de contrainte σ_{Ha}/σ_v suivants:

Profondeur	σ_v	σ_{Ha}	σ_{Ha}/σ_v
625 m:	0,0224 MPa/m	0,0304 MPa/m	1,4
990 m:	0,0253 MPa/m	0,0348 MPa/m	1,5
1 220 m:	0.0254 MPa/m	0,0467 MPa/m	1,8

L'augmentation des contraintes verticales et horizontales déterminées qui se produit en fonction de la profondeur est conforme aux tendances observées dans le Nord-Ontario.

La contrainte de compression maximale la plus importante, σ_1, est horizontale en direction nord-est. Dans les zones minérales à pentes abruptes en direction nord-ouest ou nord, σ_1 est presque orthogonal.

La détermination des contraintes dans les piliers indique que le transfert maximal des contraintes se produit horizontalement d'un côté à l'autre des piliers au point de soutirage, perpendiculairement au toit de faille et à la paroi inférieure. Des contraintes maximales de 17 à 78 MPa et des contraintes minimes d'ordre et de tension peu élevés ont été mesurées. Les contraintes dans les piliers se sont avérées moins élevées que prévu. On en conclu que les piliers ont atteint un niveau de résistance maximal et qu'ils sont à l'épreuve de la détérioration.

Les contraintes dans les piliers n'étaient pas plus élevées que l'ensemble des contraintes in situ observées à la mine Campbell de Red Lake.

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CONTENTS

	Page
ABSTRACT	i
RESUME	iii
INTRODUCTION	1
GEOLOGICAL SETTING	1
FIELD STRESS MEASUREMENTS	2
LABORATORY TESTING	9
PILLAR STRESS MEASUREMENTS	11
DISCUSSION OF RESULTS	17
ACKNOWLEDGEMENTS	21
REFERENCES	22
APPENDIX	A-23

FIGURES

No.		
1.	Stress determination sites and test hole locations on the 14, 22 and 27 levels, Campbell Red Lake Mine	3
2.	Orientation of the principal compressive stresses from Grid North in an equal area net, lower hemisphere projection	8
3.	Pillar stress determination sites and the direction of maximum stresses from Grid North on the 9 level, Campbell Red Lake Mine	14
4.	Pillar stress determination site and the direction of maximum stresses from Grid North on the 10 level, Campbell Red Lake Mine	15
5.	Pillar stress determination site and the direction of maximum stresses from Grid North on the 14 level, Campbell Red Lake Mine	16
6.	Increase of vertical stress, average horizontal stress with depth, and variation of stress ratio as a function of depth in the Canadian Shield	19

TABLES

1.	Strain recovery from triaxial strain cell measurements, Campbell Red Lake Mine	4
2.	Stress tensor components from elastic strain recovery measurements, Campbell Red Lake Mine	6
3.	Magnitude and orientation of the principal stresses from elastic strain recovery measurements, Campbell Red Lake Mine	7
4.	Determination of elastic modulus and Poisson's ratio in uniaxial compression tests	10

No.		Page
5.	Strain recovery from biaxial strain cell measurements, Campbell Red Lake Mine	12
6.	Pillar stress magnitude and direction from biaxial strain cell measurements, Campbell Red Lake Mine	13
7.	Evaluation of field stresses, Campbell Red Lake Mine	18

INTRODUCTION

Increasingly, the phenomenon of rockbursts is routinely experienced by some deep hard rock mines currently operating in Northern Ontario. Obviously, the stress appears to be one of the significant parameters. To obtain a better knowledge of stress distribution, there is a need to determine the pre-mining stress as well as pillar stresses in rockburst prone mines.

At Campbell Red Lake Mine (CRL Mine), many ground problems and rockbursts were encountered. Observations of rockbursts confirmed that the most affected areas were the boxhole and sill pillars, where shrinkage mining methods were employed (1).

Stress measurements had not been taken at CRL Mine. A cooperative project was, therefore, carried out to determine the in situ field stress as well as pillar stresses. The field stress measurements were performed in the development drifts, on the 14, 22 and 27 levels using triaxial strain cells. Mining stresses were measured in four boxhole pillars on the 9, 10 and 14 levels using biaxial strain cells. The overcoring testing procedure was used for the elastic strain recovery measurements. A total of 9 triaxial, and 15 biaxial measurements were attempted.

GEOLOGICAL SETTING

Campbell Red Lake Mine is situated at Balmertown in the Red Lake District of Northwestern Ontario. The area forms a part of the Birch-Uchi Lake greenstone belt of the Archean Superior Province. The steeply-dipping gold-bearing ore zones with a main NW/SE trend occur in a variety of geological settings. In general, ore zones are aligned parallel or oblique to the main foliation and planar structures, which were progressively fractured and infilled (2). Two major types of mineralization have been distinguished;

quartz carbonate veins 0.25 to 1 m thick, and silicified replacement veins 0.6 to 9 m thick. Most ore zones consist of a mixture of these two types of mineralization. The ore zones are designated as 'A', 'F', 'L' and 'G' zones. The metabasalt and andesite rock unit is the host of the major ore zones.

The main shaft is 1315 m deep with levels established at 45 m intervals. The production is from shrinkage and cut-and-fill stopes from a depth of 300 to 900 m.

FIELD STRESS MEASUREMENTS

Three-dimensional strain recovery measurements were carried out on the 14, 22 and 27 levels, 625 m, 990 m and 1220 m below surface, respectively. The measurements were taken in a fine-grained andesite rock and away from the influence of mining. In the vicinity of the these sites no major structural weakness plane was exposed. The test holes were drilled nearly orthogonal to the main structural trend. The orientation and location plans are shown in Figure 1. The tests were commenced at distances greater than 3.0 m from the wall of the development drifts, which were about 2.6 m square.

A total of nine strain recovery measurements were performed, three successful tests on each site. South African CSIR triaxial strain cells were used. Details of the overcoring test procedure and the specifications of the strain cell are given in the literature (3,4). In principle, the oriented strain cell is grouted into the EX-size hole which has been centrally drilled in the end of a 150 mm diameter hole. The strain readings are recorded before and after overcoring and the elastic strain recovery is obtained.

The elastic strain recoveries from triaxial strain cell measurements are given in Table 1. As shown in Table 1, the outlier readings of individual gauges are determined by strain invariances for each strain cell rosette. In most cases, a strain invariance of less than 40 micro-strain was obtained.

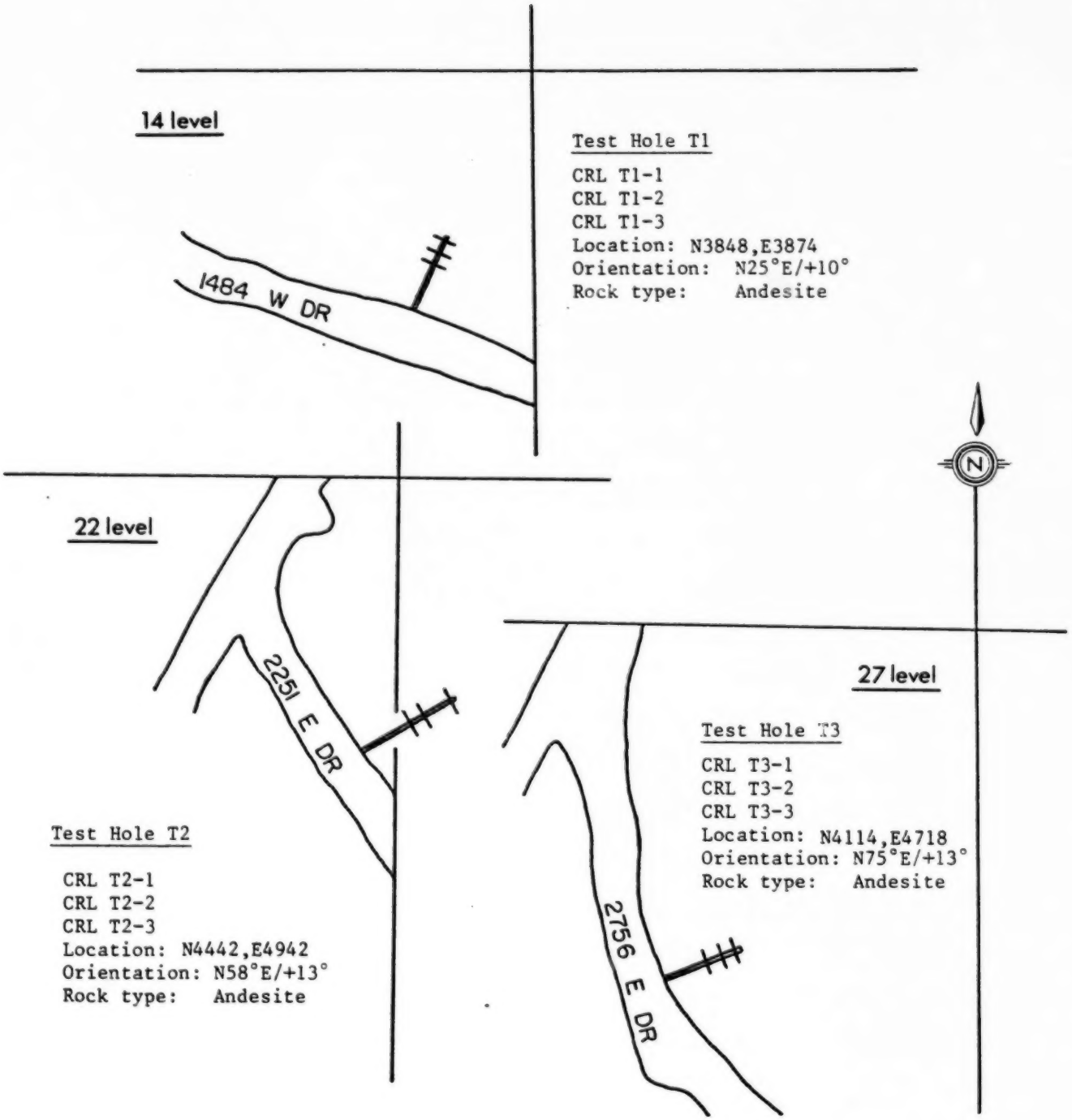


Fig. 1 - Stress determination sites and test hole locations on the 14, 22 and 27 levels, Campbell Red Lake Mine (approx. scale 1:360).

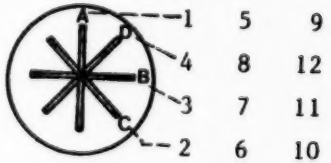
Table 1 - Strain recovery from triaxial strain cell measurements, Campbell Red Lake Mine.

Depth Below Surface	Test No.	Test Depth (m)	Gauge No.: Rosette No. 1				Rosette No. 2				Rosette No. 3				SI(*) Rosette No:		
			1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
625 m 14 L	CRL T1-1	3.90	120	235	190	185	120	340	345	130	140	100	60	110	110	5	10
	CRL T1-2	4.30	295	270	130	145	495	235	105	370	80	100	90	80	10	5	10
	CRL T1-3	5.00	135	185	120	80	350	100	145	420	390	280	160	200	10	25	70
990 m 22 L	CRL T2-1	3.50	420	820	360	-80	240	30	395	610	650	340	340	640	40	5	10
	CRL T2-2	4.40	365	525	250	100	580	60	270	770	340	415	295	230	10	20	10
	CRL T2-3	6.00	675	1240	380	-195	570	-300	376	1230	415	450	400	280	10	16	85
1220 m 27 L	CRL T3-1	3.25	445	670	275	15	150	250	900	695	950	905	1300	1160	35	105	185
	CRL T3-2	4.15	820	35	-225	525	500	1175	1425	725	790	1765[x]	1385[x]	1960[x]	35	25	1550
	CRL T3-3	4.90	915	-30	-225	655	640	1450	1425	750	850	1890[x]	1715[x]	2020[x]	65	135	1345
															$\bar{x}$ = 41.84		
															STDV = 47.86		

(*) Strain invariance

(x) Readings omitted from stress tensor calculation

Strain gauge configuration for rosettes:



Gauge No.:			
1	5	9
4	8	12
3	7	11
2	6	10
Rosette:	1	2	3

From theory, the sum of the strains measured by gauges at right angles to each other is constant for isotropic and homogeneous material: $E_A + E_B - E_C - E_D = 0$. This equation cannot be expected to apply exactly for the rock type encountered, which showed some localized variations and inhomogeneity throughout the test holes.

Table 2 provides the results of stress tensor analysis. The mean values of elastic modulus and Poisson's ratio from Table 4, were taken for stress tensor calculations. As a result of poor cell-rock bonding some outlier gauge readings were observed in CRL T3-2 and CRL T3-3 tests. These readings were rejected and omitted from the final calculations. The standard errors for most measurements were in an acceptable range. However, because of some rejected readings the tensor calculations for CRL T3-2 and CRL T3-3 tests resulted in high standard errors and deviations.

The principal compressive stress magnitudes and orientations with regard to the true north (= Mine Grid North) are given in Table 3. Figure 2 illustrates graphically the orientation of principal compressive stresses for individual measurements and the mean direction of the maximum principal compressive stress. The directions of principal stresses for individual test sites are relatively consistent. Maximum principal compressive stress, σ_1, orientation on the 14, 22 and 27 levels is in general agreement, and a horizontal NE/SW and EW trend prevails. The direction of σ_1 on the 22 level shows a rotation of 30^o to 40^o clockwise from the main orientation of σ_1 obtained on the 14 and 27 levels. With regard to the orientation, intermediate, σ_2, and minimum, σ_3, principal compressive stresses indicated some scatter, but generally, σ_2 is vertically and σ_3 is sub-horizontally oriented.

Table 2 - Stress tensor components from elastic strain recovery measurements, Campbell Red Lake Mine.

Test No.	Stress Components in MPa (1) (Standard errors in brackets)						(2) q (10^3)	STDV	Elastic Modulus (GPa)	Poisson's Ratio
	σ_x	σ_y	σ_z	τ_{xy}	τ_{yz}	τ_{zx}				
CRL T1-1	8.4 (2.95)	9.0 (2.95)	22.8 (4.82)	-1.0 (1.68)	-0.6 (2.31)	2.4 (2.31)	67.30	0.73	91.7	0.21
CRL T1-2	14.8 (0.35)	15.2 (0.34)	16.3 (0.55)	-5.8 (0.19)	2.3 (0.27)	-1.7 (0.27)	0.90	0.08	91.7	0.21
CRL T1-3	19.0 (0.80)	11.5 (0.80)	19.1 (1.31)	0.18 (0.46)	2.8 (0.63)	-4.3 (0.63)	5.02	0.20	91.7	0.21
CRL T2-1	23.6 (0.85)	22.4 (0.85)	40.9 (0.95)	5.0 (0.33)	15.6 (0.45)	-2.8 (0.45)	3.05	0.15	85.3	0.22
CRL T2-2	23.4 (0.60)	20.4 (0.60)	32.8 (0.99)	-2.8 (0.34)	8.0 (0.47)	-9.0 (0.47)	3.25	0.15	85.3	0.22
CRL T2-3	25.2 (0.56)	31.0 (0.56)	44.5 (0.93)	-2.2 (0.32)	24.3 (0.44)	-17.1 (0.44)	2.86	0.15	85.3	0.22
CRL T3-1	33.6 (8.6)	23.5 (8.6)	79.1 (14.0)	11.5 (4.9)	11.8 (6.8)	-1.9 (6.8)	0.67 (10^6)	2.3	84.8	0.20
CRL T3-2	39.6 (22.5)	32.5 (20.5)	63.7 (41.4)	0.22 (13.1)	-8.6 (19.7)	4.1 (25.5)	1.87 (10^6)	5.4	84.8	0.22
CRL T3-3	45.3 (22.9)	36.8 (20.9)	68.0 (42.0)	-1.3 (13.4)	-12.1 (20.0)	7.3 (25.9)	1.93 (10^6)	5.5	84.8	0.22

(1) x, y, z are coordinates of an orthogonal right-handed coordinate system. x^+ is on right-hand side when looking down the drill hole; y^+ is vertical; z^+ is parallel to the drill hole direction and points towards the collar.

(2) Residual sum of squares.

Table 3 - Magnitude and orientation of the principal stresses from elastic strain recovery measurements, Campbell Red Lake Mine.

Test No.	σ_1 MPa	Brg./Dip*	σ_2 MPa	Brg./Dip	σ_3 MPa	Brg./Dip
CRL T1-1	23.2	203/09	9.5	106/30	7.4	308/59
CRL T1-2	22.2	082/38	14.9	188/20	9.2	300/59
CRL T1-3	23.7	037/42	15.7	241/46	10.2	138/12
CRL T2-1	49.8	268/00	26.1	358/66	10.9	178/24
CRL T2-2	41.6	082/27	19.1	309/53	15.8	182/22
CRL T2-3	68.6	092/20	25.1	329/52	7.0	195/31
CRL T3-1	81.5	260/01	40.7	350/60	14.1	169/31
CRL T3-2	66.6	234/08	39.2	010/78	30.1	143/08
CRL T3-3	74.0	228/14	43.5	028/75	32.5	138/05

* Bearing in degrees clockwise from Grid North (Grid North = True North); dip is the angle in degrees from horizontal. Triaxial strain cells were installed with $x^+ = 12^\circ$ above horizontal, $y^+ = 12^\circ$ counter clockwise from vertical.

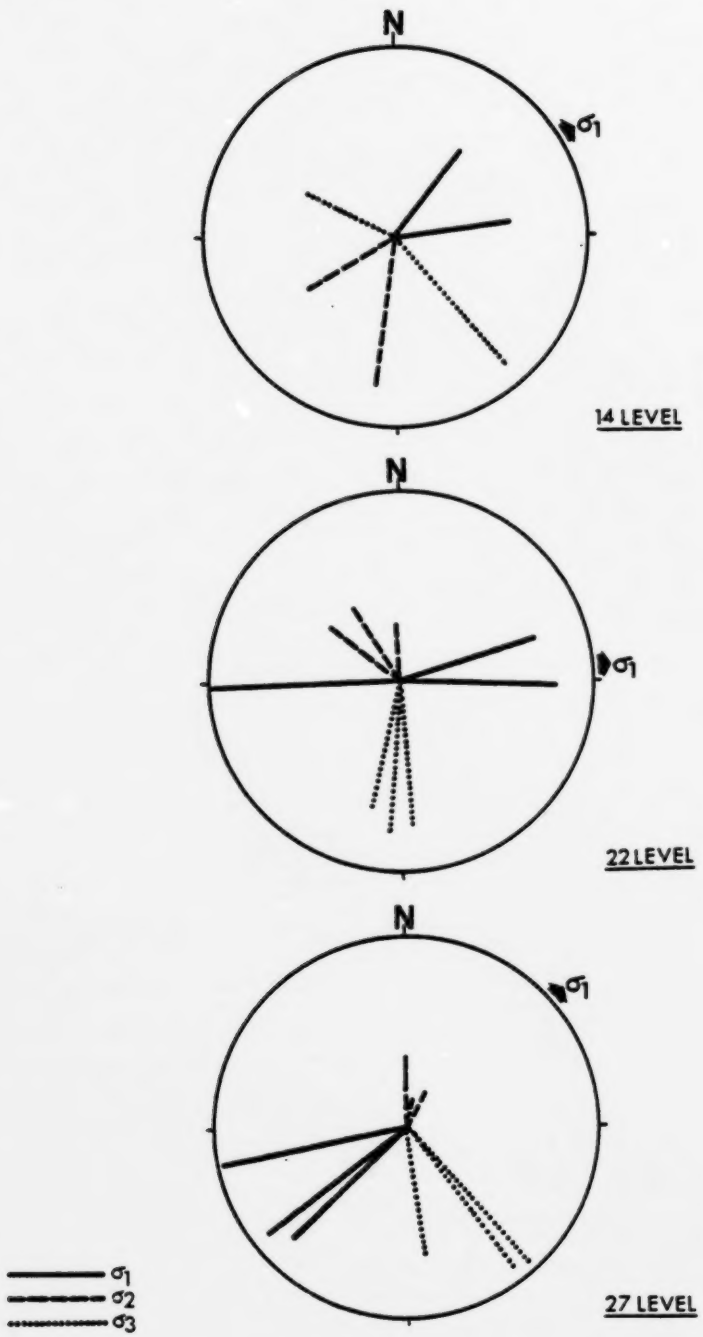


Fig. 2 - Orientation of the principal compressive stresses from Grid North in an equal area net, lower hemisphere projection, (Grid North = True North). ◗ σ_1 mean direction.

LABORATORY TESTING

For determination of the elastic constants, the overcored test specimens and all available intact cores with a diameter of ~136 mm were selected. The cores were cut to a height/diameter ratio of 2.5 and the ends were prepared to a parallelism of 0.05 mm. Each sample was fitted with two pairs of strain gauges at mid-height in the vertical and longitudinal directions. Samples were axially loaded to a maximum pressure of 37 MPa and unloaded to zero. Gauge readings in the unloading cycles for the intervals of 12 to 25 MPa were used to calculate the elastic moduli, and Poisson's ratios were determined by the ratio of vertical to longitudinal strain at maximum compression. The results are given in Table 4. The mean values of the elastic moduli and Poisson's ratios from uniaxial compression tests were used for stress tensor calculations.

In all test locations, quartz-carbonate filled fractures were encountered throughout the cores, which resulted in some variations in the elastic properties.

The prepared hollow overcored specimens containing the strain cell were subjected to axial loading to determine gauge response for linearity and zero shift. One loading cycle was performed and strain readings were obtained for individual gauges. The plots of gauge responses for available intact overcored tests are shown in the Appendix.

All core samples were kept for further tests of uniaxial compressive strengths and post-failure characteristics after the modified 18 MN Gilmore press in the Elliot Lake Laboratory is put in operation. The results will be presented in the future.

Table 4 - Determination of elastic modulus (E) and Poisson's ratio (V) in uniaxial compression tests.

Sample No.	E* GPa	V*	E^{x} GPa	V^{x}	Remarks
CRL T1-1	91.0	0.20	-	-	Cell broke off
CRL T1-2	88.2	0.24	81.0	0.19	
CRL T1-3	91.3	0.21	82.0	0.23	
CRL T1A	97.7	0.21			
CRL T1B	90.4	0.21			
CRL T1C	-	-			Sample failed during loading
Mean:	91.7±3.55	0.21±0.01			
CRL T2-1	76.3	0.20	85.5	0.22	
CRL T2-3	-	-	99.3	0.23	Height/diameter ratio 1:9
CRL T2A	84.3	0.23			
CRL T2B	90.5	0.20			
CRL T2C	94.0	0.22			
CRL T2D	81.4	0.24			
Mean:	85.3±7.07	0.21±0.01			
CRL T3-2	73.8	0.20	88.9	0.24	Sample fractured
CRL T3A	90.5	0.21			
CRL T3B	81.4	0.19			
CRL T3C	93.8	0.22			
Mean:	84.8±9.05	0.20±0.01			

* Obtained during unloading cycle in intervals of 12 to 25 MPa; maximum load 37 MPa.

x Obtained from strain reading of the axial and circumferential gauges of strain cell.

Note: Sample diameter ∿136 mm; height/diameter ratio: 2.48±0.01.

PILLAR STRESS MEASUREMENTS

Pillar stresses were determined in four boxhole pillars in the "F2" zone on the 9, 10 and 14 levels (400 m, 440 m and 625 m below surface). Figures 3, 4 and 5 show the test locations and the layout of the pillars. The measurements were carried out in BW-size drillholes yielding a core of 44 mm nominal diameter. The vertical boreholes ($+90^{o}$) were drilled in the centre section of the boxhole pillars having a height of about 4.5 m and a width of 5.5 m.

For strain recovery measurements, a four-gauge CSIR biaxial strain cell (doorstopper) was used. The principle is to measure the rock strain by overcoring with the strain cell cemented to the flattened end of the test hole (5).

In all measurements, the vertical gauge (S1) of the strain cell was aligned towards North in the mine grid system. The accuracy of orientation was approximately $\pm 5^{o}$ from the Mine Grid North. An effort was made to keep the test distances along the boreholes identical. A total of fifteen measurements were attempted. Despite all precautions two tests indicated erratic values because of insufficient cell-rock bonding and instrument malfunctions. These were omitted in the final analysis.

Test locations, setting depth and the strain recovery data are given in Table 5. Table 6 provides the calculated magnitude and direction of pillar stresses. The directions of maximum stress for individual measurements are also displayed in the plane views in Figures 3 to 5. The mean values for elastic modulus of 83 GPa and Poisson's ratio of 0.20, obtained from axial loading tests (Table 4) were used for stress calculations.

An analysis of pillar stresses revealed the following results: the mean maximum principal stress in the boxhole pillars varies between 25 to 65

Table 5 - Strain recovery from biaxial strain cell measurements, Campbell Red Lake Mine.

Location	Test No.	Test Depth (m)	Strain Recovery (10^{-6} in/in) NS S1	45°L S2	EW S3	45°R S4	SI*
902-1 W DR.	CRL 1-1[x]	1.70	185	4	-182	-2	1
No. 8 pillar	CRL 1-2	2.00	23	-360	-24	355	4
	CRL 1-3	2.40	156	-8	102	272	6
	CRL 1-4	2.50	320	-13	30	398	35
	CRL 1-5	2.80	449	575	170	9	35
902-1 E DR.	CRL 2-1	1.75	186	642	393	-69	6
No. 2 pillar	CRL 2-2[x]	2.10	70	223	126	-22	5
	CRL 2-3	2.20	732	656	13	60	29
	CRL 2-4	2.50	688	590	-12	42	44
1002-1 W DR.	CRL 3-1	2.40	850	686	-242	-22	56
No. 13 pillar	CRL 3-2	2.60	711	615	-110	-38	24
1459 E DR.	CRL 4-1	1.95	-218	723	1300	334	36
No. 16 pillar	CRL 4-2	2.10	-304	-155	745	607	11
	CRL 4-3	2.30	-167	548	950	222	13
	CRL 4-4	2.60	-177	700	1240	344	19

[x] Tests with poor bonding, omitted from stress tensor calculation.

* Strain invariance, according to elastic theory (6): S1 + S3) - (S2 + S4) = 0.

Note: All test holes are vertical (+90°) and the vertical gauge of strain cell (S1) is oriented in the NS direction of the Mine Grid System.

Table 6 - Pillar stress magnitude and direction from biaxial strain cell measurements, Campbell Red Lake Mine.

Location	Test No.	Maximum Stress MPa	Minimum Stress MPa	Direction* of Max. Stress
902-1 W DR.	CRL 1-2	18.0	-18.0	47°
No. 8 pillar	CRL 1-3	17.0	2.0	50°
	CRL 1-4	27.0	1.0	64°
	CRL 1-5	37.0	6.0	123°
	Mean:	25.0±9.3	Overall direction:	NNE
902-1 E DR.	CRL 2-1	40.0	3.0	-37°
No. 2 pillar	CRL 2-3	49.0	4.0	111°
	CRL 2-4	45.0	2.0	110°
	Mean:	45.0±4.5	Overall direction:	NW
1002-1 W DR.	CRL 3-1	58.0	-8.0	106°
No. 13 pillar	CRL 3-2	47.0	-4.0	110°
	Mean:	53.0±7.8	Overall direction:	NNW
1459 E DR.	CRL 4-1	78.0	-0.1	-7°
No. 16 pillar	CRL 4-2	49.0	-15.0	18°
	CRL 4-3	58.0	-0.5	-8°
	CRL 4-4	75.0	2.0	-7°
	Mean:	65.0±13.8	Overall direction:	EW

* Angles counter-clockwise (positive) from horizontal E-W.

Note: Elastic modulus = 83GPa, and Poisson's ratio = 0.20, were used for stress calculation.

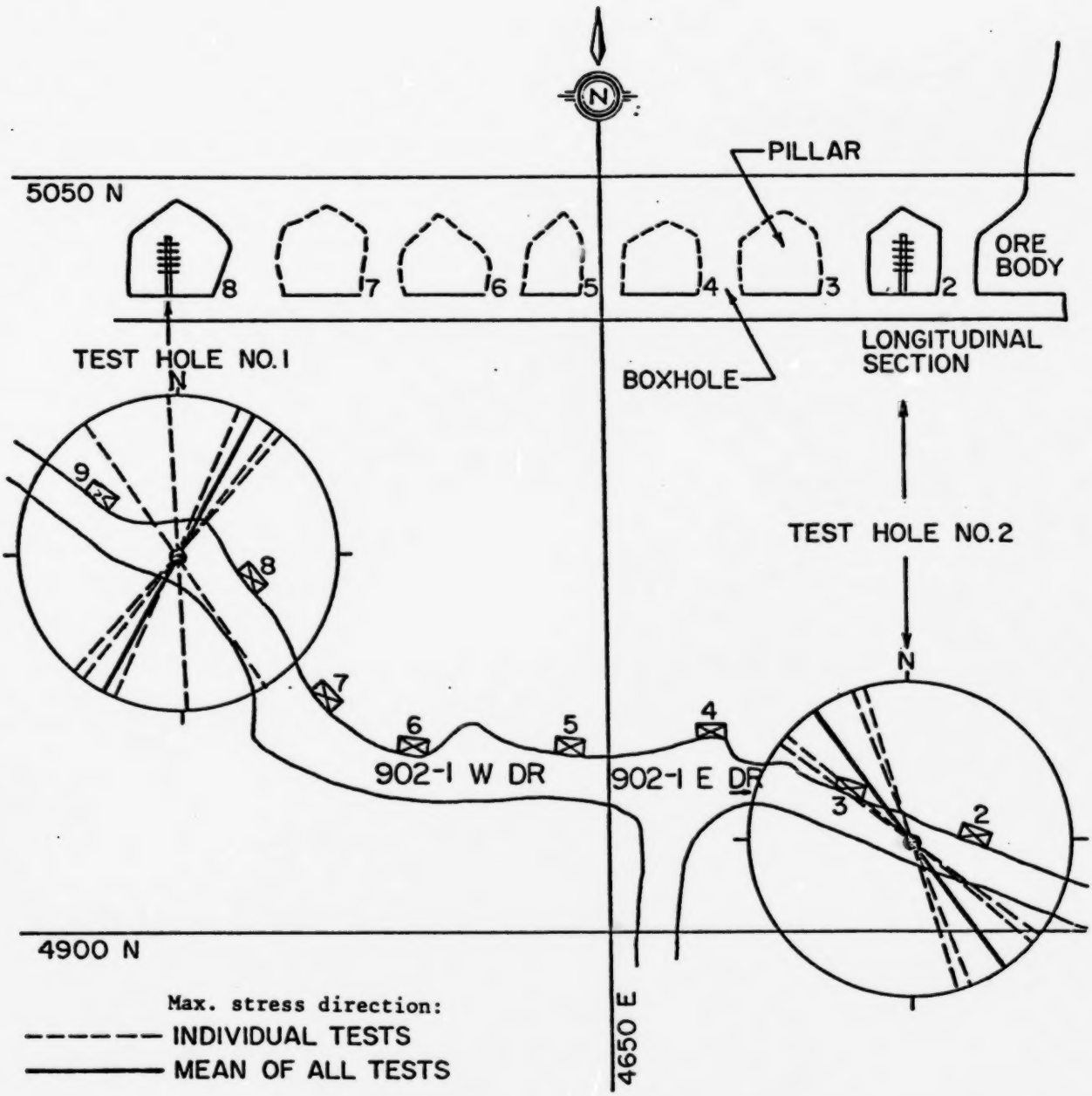


Fig. 3 - Pillar stress determination sites and the direction of maximum stresses from Grid North on the 9 level, Campbell Red Lake Mine (approx. scale 1:360).

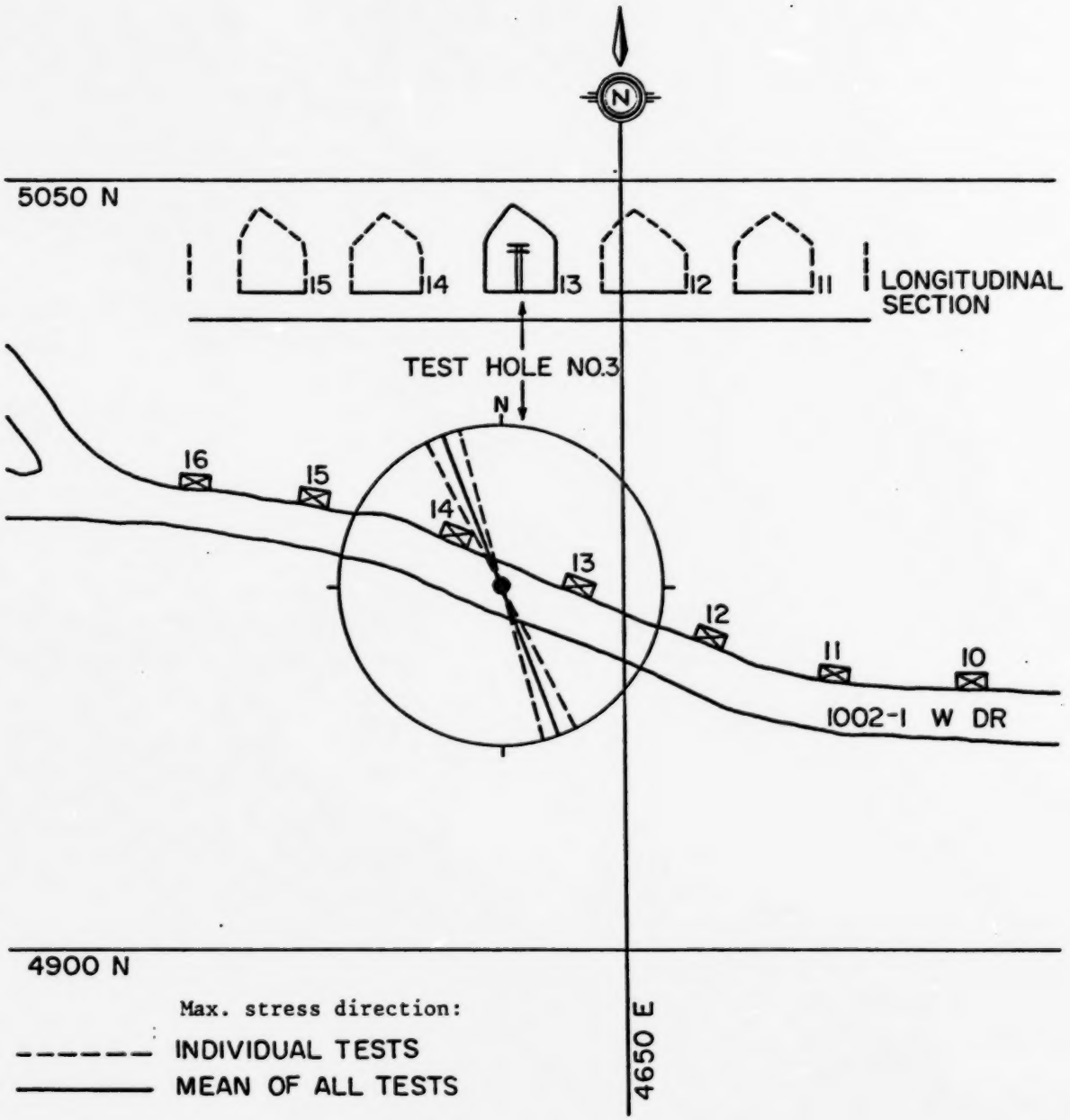


Fig. 4 - Pillar stress determination site and the direction of maximum stresses from Grid North on the 10 level, Campbell Red Lake Mine (approx scale: 1:360).

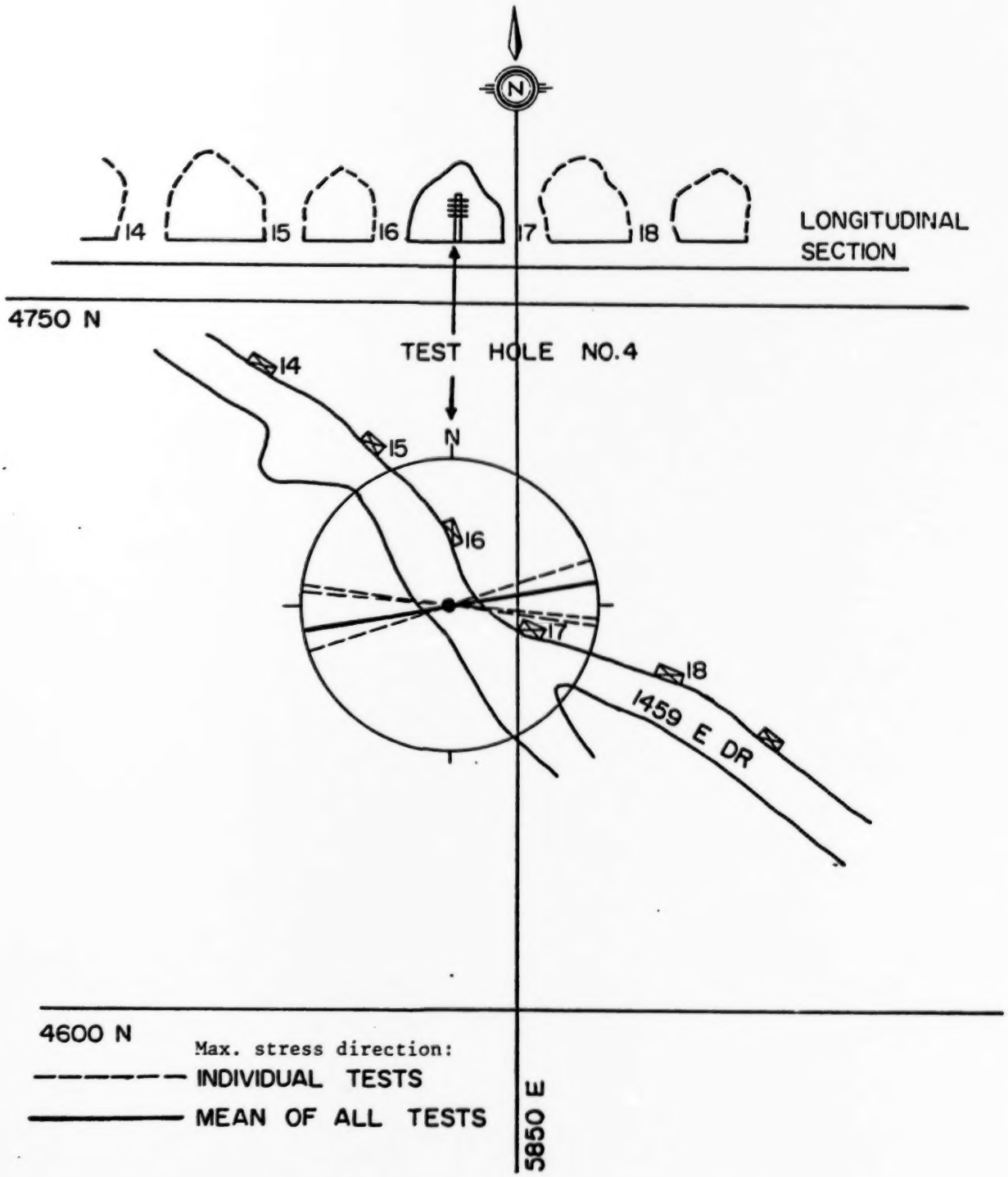


Fig. 5 - Pillar stress determination site and the direction of maximum stresses from Grid North on the 14 level, Campbell Red Lake Mine (approx. scale 1:360).

MPa and acts, depending on excavation geometry, nearly in North-South and East-West direction. This reflects the expected horizontal stress approximately perpendicular to the mining excavations and the hanging wall/footwall. In most cases, minimum stresses of low order, or tensional, were recorded with directions nearly parallel to the mining excavations.

When comparing the stress magnitudes, lower stresses were measured on the 9 level rather than on the 10 and 14 levels, indicating a stress increase from 9, 10 to 14 level. Consequently, No. 16 boxhole pillar on 14 level is subjected to higher stress concentrations than the pillars on the 9 and 10 levels.

Comparing the measurements on the 9 level, the stress magnitude and direction obtained from No. 2 boxhole pillar is largely affected by the mining geometry, i.e., unmined section in the proximity of the test location. As a result of partially fractured pillars, variations in stress magnitudes were observed; lower stresses were measured particularly where open fractures occurred in some test locations.

DISCUSSION OF RESULTS

After screening and evaluation the field stress determinations, the most representative data were summarized. Table 7 shows the mean values for the principal stresses, vertical stress, σ_V, average horizontal stress, σ_{Ha}, and the stress ratio, σ_{Ha}/σ_V. From stress determinations in the Canadian Shield (7,8), good background information exists which allows a comparison with the data obtained from CRL Mine. Therefore, a comparison was made between the measured values and the data from Northern Ontario, the results are included in Table 7 and plotted in Figure 6. The data are in general agreement, particularly regarding the magnitudes of vertical stress, confirming the validity of the measurements. However, it appeared that the

Table 7 - Evaluation of field stresses, Campbell Red Lake Mine.

Depth Below Surface	Test No.	Field Stresses (in MPa), CRL Mine σ_1 Brg./Dip	σ_2 Brg./Dip	σ_3 Brg./Dip	σ_v % Diff.[x]	σ_{Ha} % Diff.	σ_{Ha}/σ_v % Diff.	Northern Ontario Data* (MPa)
625 m	CRL T1-2	23	15	10	14	19	1.4	σ_v=16, σ_{Ha}=33
(14 L)	CRL T1-3	060°/40°	214°/33°	134°/33°	12%	42%	6%	σ_{Ha}/σ_v=1.5
	combined							
990 m	3 test	53	24	12	25	38	1.5	σ_v=26, σ_{Ha}=44
(22 L)	combined	087°/16°	322°/57°	185°/26°	4%	13%	7%	σ_{Ha}/σ_v=1.4
1220 m	CRL T3-2	70	41	31	34	55	1.6	σ_v=32, σ_{Ha}=47
(27 L)	CRL T3-3	230°/10°	020°/76°	140°/07°	6%	17%	14%	σ_{Ha}/σ_v=1.4
	combined							

[x] Differences of vertical (σ_v), average horizontal (σ_{Ha}) stresses and stress ratio (σ_{Ha}/σ_v) with Northern Ontario data.

* Northern Ontario data, obtained from stress gradients in the Canadian Shield (7,8) defined as:

σ_v = 0.027 MPa/m (obtained from overburden weight).

σ_{Ha} = 9.86 MPa + 0.0371 MPa/m (0-900 m depth below surface).

σ_{Ha} = 33.41 MPa + 0.0111 MPa/m (900-2200 m depth below surface).

$$\sigma_{Ha}/\sigma_v = \frac{251.68}{\text{depth m}} + 1.14$$

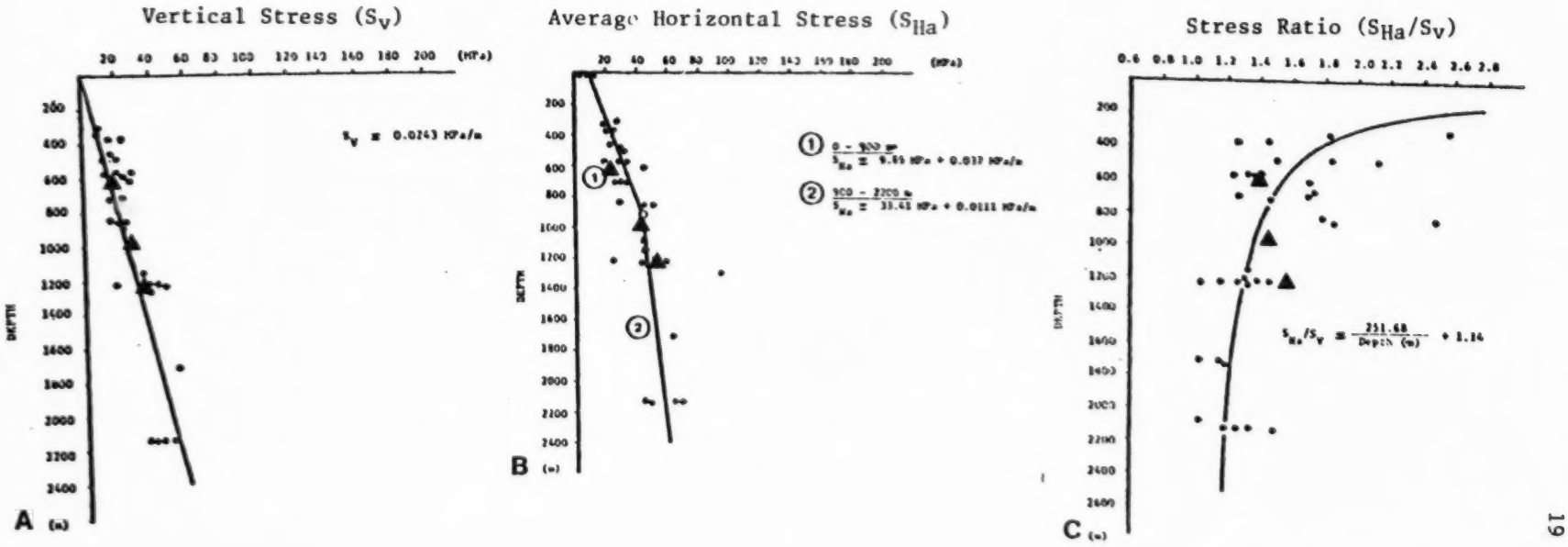


Fig. 6 - Increase of vertical stress (A), average horizontal stress (B) with depth, and variation of stress ratio as a function of depth (C) in the Canadian Shield, after Herget (7). Extreme values were excluded for ease of comparison. Values at Campbell Red Lake Mine (▲).

measured horizontal stress on the 14 level lay about 40% below, and on the 27 level 17% above the expected values. As a result of some local tectonic disturbances the differences are not unexpected.

The measurements indicated that the stress magnitudes are relatively variable and reflect rock inhomogeneity, but approach in many cases the overburden pressure. Some scatter was observed for individual sites, but good consistency existed for the maximum principal compressive stress, σ_1, prevailing in a northeasterly direction. Generally, the intermediate principal compressive stress, σ_2, is sub-vertical, while the minimum principal compressive stress, σ_3, shows a sub-horizontal direction. This indicates an anomaly with regard to the stress distribution when compared with the overall trend observed for Northern Ontario.

With regard to the steeping dipping ore zones, 'A' and 'F' zones with NW-SE trends, 'G' and 'L' zones in a northerly direction, the maximum principal compressive stress direction is orthogonal.

From the ground stress determinations, the pre-mining horizontal stresses perpendicular and parallel to the ore zones at CRL Mine can be approximated as follows:

Location	Horizontal Stress O/B (MPa)	O/B (MPa)	Vert. Stress σ_v (MPa)	Stress Ratio $\frac{\sigma H}{\sigma_v}$	$\frac{\sigma H}{\sigma_v}$
14 level	23.0	16.0	16.0	1.4	1.0
22 level	54.0	24.0	26.0	2.0	0.9
27 level	73.0	43.0	32.0	2.3	1.3

The measured pillar stresses are, in all cases, not higher than the general field of undisturbed stresses obtained on the 14, 22 and 27 levels at

CRL Mine, only a few hundred metres away.

Ground stresses determined in the boxhole pillars are found to be subjected to some dispersion. The variations in the geometry of the pillars, stopes and the mining boundaries might explain this dispersion.

No significant sign of high pressure or deterioration was seen in the boxhole pillars where the stress measurements were taken. From the previous investigations (1), it was found that rockbursts occurred as the hanging wall and footwall converged as a result of pillar failure. In addition, computer-determined stress distributions indicated a critical stress level in the range of 120 MPa for the boxhole pillars. The measured boxhole pillar stresses are 80 to 60% on the 9 level, 55% on the 10 level, and 45% on the 14 level, of the estimated peak strength. It is thought that these boxhole pillars have exceeded their peak strength and are now in post-failure conditions. The measured stresses probably do not represent residual strength values as the adjoining crown pillars have not yet failed and a further reduction in stress could occur when this happens.

The stresses determined are regarded as an acceptable estimate of in situ stress as well as pillar stresses at CRL Mine. However, it appears that more measurements are required at different locations to provide quantitative field data in order to extrapolate the data to the regional scale of the mine.

ACKNOWLEDGEMENTS

The cooperation of Campbell Red Lake Mines Ltd., especially M. Neumann, Chief Engineer, and T. Makuch, Ground Control Engineer, is appreciated. Campbell Red Lake Mine provided the manpower, drilling equipment and strain cells for this project.

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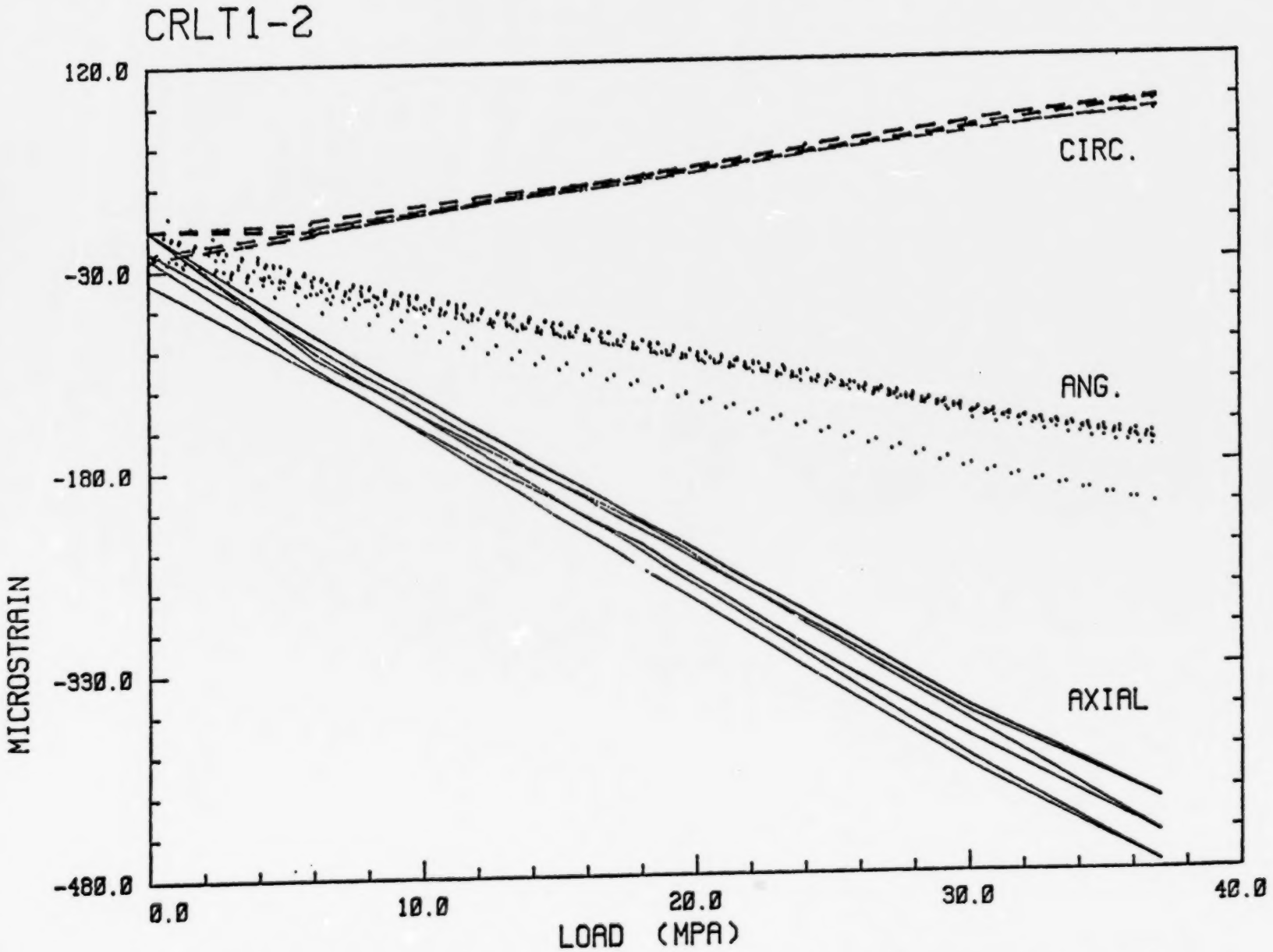

Fig. A-1 - Gauge response and linearity from loading cycle in uniaxial compression CRL T1-2.

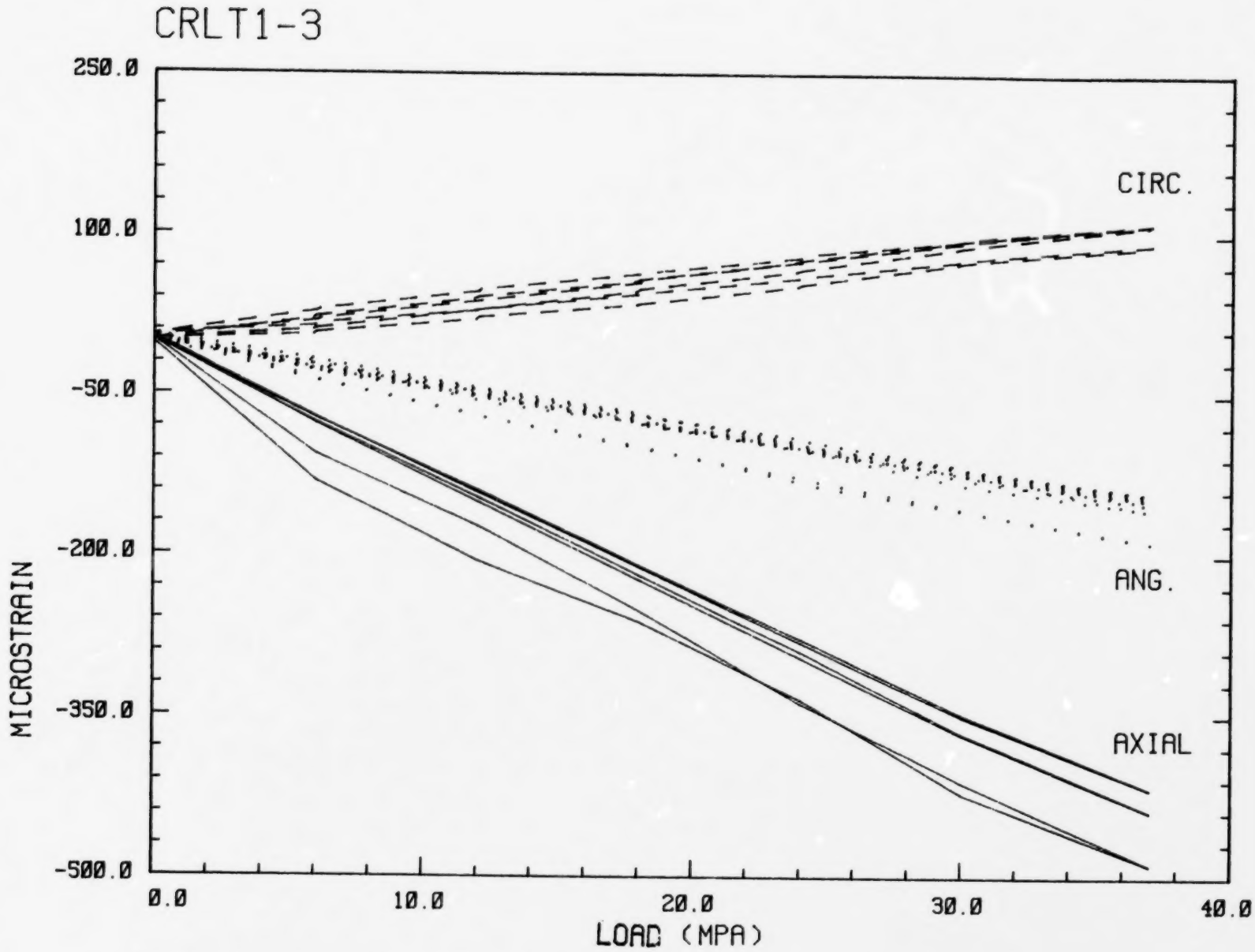

Fig. A-2 Gauge response and linearity from loading cycle in uniaxial compression, CRL T1-3.

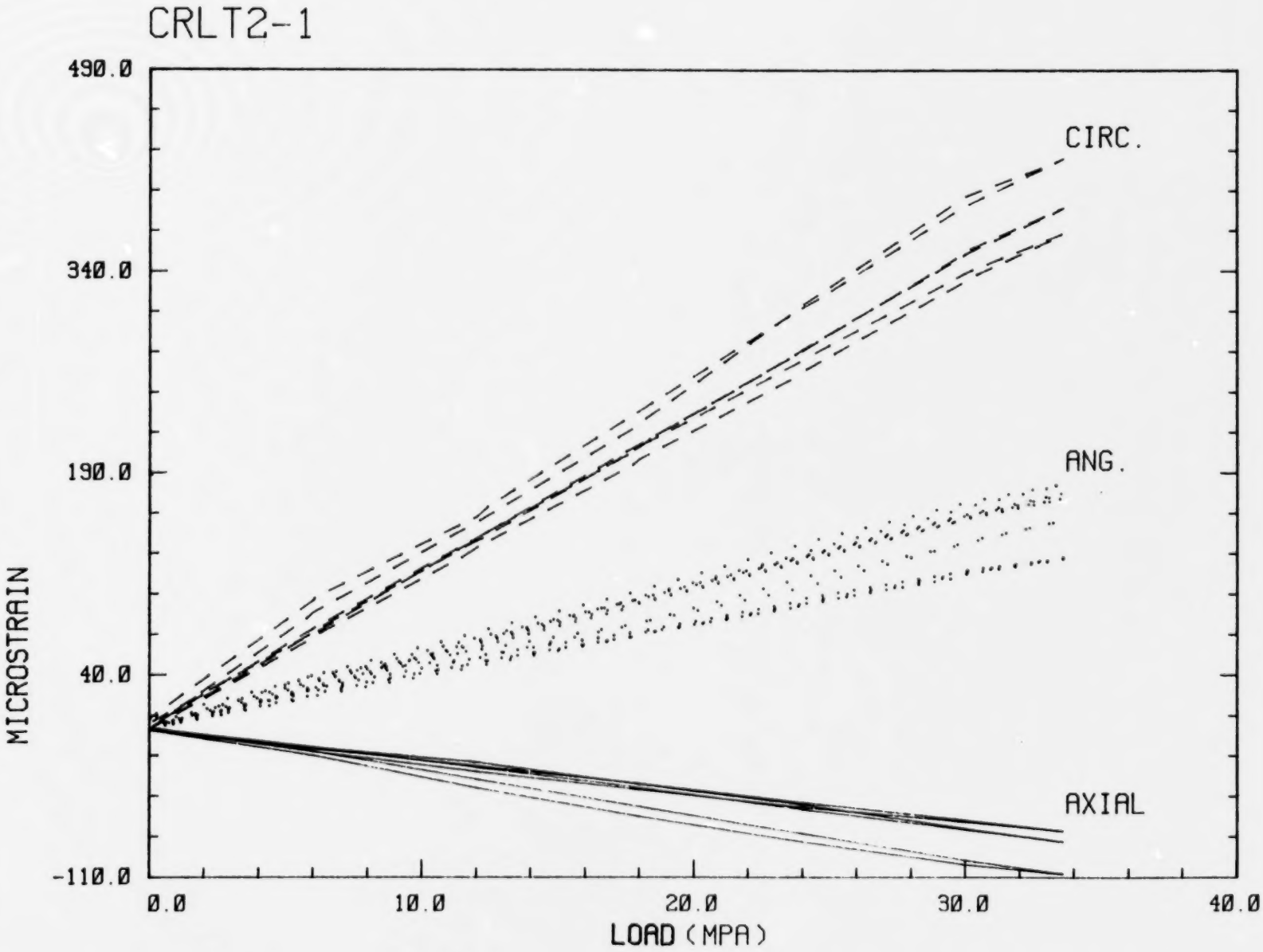

Fig. A-3 - Gauge response and linearity from loading cycle in uniaxial compression, CRL T2-1.

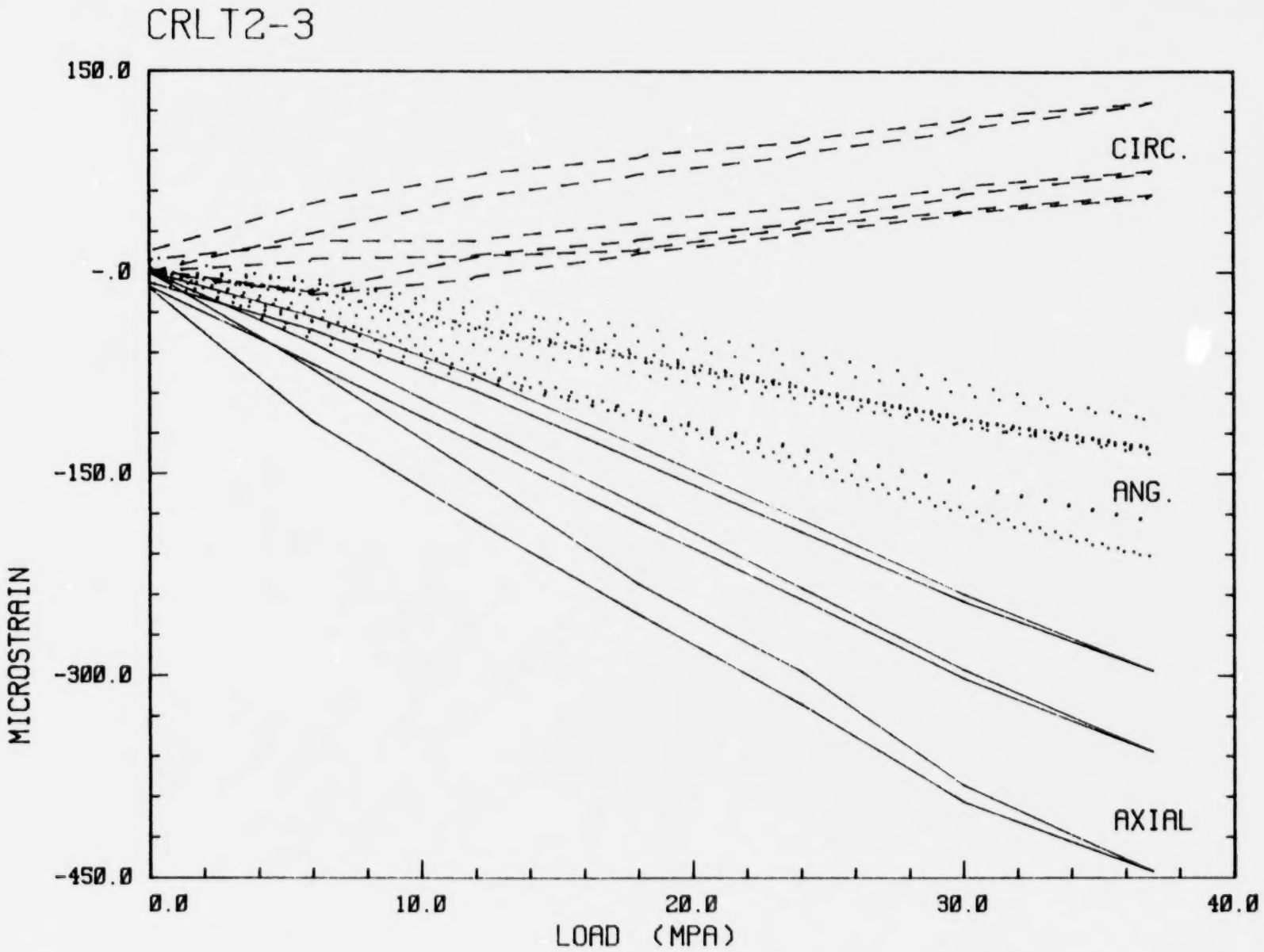

Fig. A-4 - Gauge response and linearity from loading cycle in uniaxial compression, CRL T2-3.